STEERING COLUMN MOVEMENT IN SEVERE FRONTAL CRASHES AND ITS POTENTIAL EFFECT ON AIRBAG PERFORMANCE

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ABSTRACT

Excessive movement of steering columns in crashes can significantly degrade the performance of restraints, especially airbags. Although steering column movement does not appear to be a major problem in full-width rigid barrier crashes, it can be an issue in other frontal crash types. Results from 106 frontal offset crash tests at 64 km/h (40 mi/h) were used to characterize different patterns of steering column intrusion for different vehicle types. Large movements of the steering column often were associated with the dummy's head striking the steering wheel through the airbag. Some of the tested models were redesigned over the course of this testing, and comparisons with older designs showed that improving the structural integrity of the occupant compartment could lead to less longitudinal movement of the steering column, but this was not necessarily the case for vertical column movements for some models in the data set. Multipurpose passenger vehicles—pickups, utility vehicles and passenger vans—tended to have more vertical steering column movement than cars. Examples of fatal frontal crashes from the National Automotive Sampling System/Crashworthiness Data System and serious frontal crashes from the Insurance Institute for Highway Safety's Seven-County Crash Investigation Study were examined to better understand the real-world consequences of steering column movement. Both crash samples included cases in which serious and fatal injuries were attributed to driver contact with the steering wheel despite the presence of a deployed airbag. Some examples of these injuries occurred in crashes without catastrophic collapse of the occupant compartment, and some of the drivers were belted. As crash test results suggest, movement of the steering column in frontal crashes can degrade real-world airbag effectiveness, and this phenomenon deserves more attention than it has received in the past.

INTRODUCTION

Federal Motor Vehicle Safety Standard (FMVSS) 208 specifies frontal crash protection requirements for vehicles sold in the United States. The standard prescribes passenger protection by specifying limits for measurements made on crash test dummies subjected to various crash and airbag tests. FMVSS 204, which specifies performance characteristics for the steering system, limits the amount of horizontal steering column intrusion allowed in a 48 km/h crash against a rigid wall to 127 mm. An earlier standard, FMVSS 203, limited the force on a block representing a body impacting the steering wheel at 24 km/h; this standard no longer applies to vehicles with airbags. These various standards have led to steering systems that generally include some form of collapsible, force-limiting steering column that is attached to the vehicle's interior structure through so-called shear capsules. These capsules allow the force-limiting mechanism to act under the influence of a forward-directed force on the steering wheel but inhibit rearward movement of the column.

These design elements were found to be somewhat effective at preventing steering-system-induced injuries. Kahane (1982) found fewer deaths and injuries in vehicles whose steering systems complied with FMVSS 203 and 204, compared with vehicles that did not meet these standards. Nevertheless, many injuries were still associated with steering system contacts. A study of crashes occurring in the United Kingdom found that many of the force-limiting mechanisms did not perform in real crashes the way they did in regulatory tests because off-axis forces increased the columns' resistance to collapse (Gloyns et al., 1980). Concern about the shortcomings of these designs was mitigated by the advent of driver airbags, which was associated with a significant reduction of injuries associated with steering system contacts. For example, the National Highway Traffic Safety Administration estimates that the combination of an airbag plus a lap/shoulder belt reduces the risk of serious head injury by 81 percent compared with 60 percent for belts alone (Insurance Institute for Highway Safety (IIHS), 2001a). Still, injuries continue to be associated with steering wheel contact. Augenstein et al. (1995) reported on liver and spleen injuries sustained by drivers of airbag-equipped cars and attributed some of these injuries to contact with the steering wheel, for instance. Such steering-system-induced injuries to drivers of airbag-equipped vehicles may occur because movement of the steering column during the crash puts the airbag out of the position where it can provide protection.

A laboratory re-creation of a 1991 National Automotive Sampling System (NASS) crash (case 79-021A) at IIHS's Vehicle Research Center illustrates that even in a moderately severe crash, movement of the steering column can be great enough to prevent the airbag from protecting a driver's chest (Arbelaez and O'Neill, 2001). In this re-creation, a 1991 Dodge Grand Caravan was crashed into the rear of a stationary 1958 Chevrolet Bel Air at 64 km/h. Early in the crash sequence as the airbag inflated, the steering column rotated upward and exposed the lower portion of the steering wheel rim to the unbelted dummy's chest. The dummy recorded moderately high sternum deflections, but all of its ribs were permanently deformed by this impact. The driver of the vehicle in the NASS crash died of massive chest injuries, which were attributed by the NASS investigators to bottoming out the airbag; however, the crash re-creation indicates the more likely cause was contact with the steering wheel rim due to column rotation. Other NASS cases in which occupants with airbags sustained fatal injuries also illustrate that airbag protection can be compromised when steering columns move in crashes. Further evidence on the key role of steering columns is provided by results from 64 km/h frontal offset crash tests—tests in which steering columns tend to move much more than in federally mandated 48 km/h rigid barrier tests. This paper examines the role of steering column movement in frontal crashes and the extent to which it can compromise restraint system performance.

CRASH TEST RESULTS

Since 1995, IIHS has amassed a database of more than 100 frontal offset crash tests at 64 km/h involving new vehicle designs. All of the tests were crashes against a fixed barrier with the same deformable face specified for European regulatory tests (IIHS, 2000). The crashes were offset to the driver side such that 40 percent of each vehicle's overall width was aligned with the crash barrier. Measurements from sensors in a belted Hybrid III 50th percentile male driver dummy and measurements of vehicle deformation, which included displacement of the steering column, were recorded for each test. The IIHS (2000) crashworthiness evaluation protocol describes in detail how the tests were conducted and the measurements were made.

Measurements of steering column displacement, which compare the precrash and postcrash positions of the steering wheel center, do not reflect the maximum displacement of the column end during the crash. Still, these measurements indicate the extent to which column movement is controlled by various design features. The 106 tests used in this analysis represent the frontal crash performance of 102 unique vehicle designs and show a large variation of steering column displacement even among vehicles whose occupant compartments remained relatively intact throughout the crash. Table 1 shows the range and average of column displacements in each of three directions: longitudinal (positive values represent forward displacement), lateral (positive values represent leftward movement), and vertical (positive values represent upward movement).

Table 1.
Steering Column Displacement (N=106)

	Longitudinal (cm)	Lateral (cm)	Vertical (cm)
Minimum	-21	-11	-5
Average	-3.8	0.1	9.0
Maximum	11	29	27

Even in this severe frontal crash, rearward displacement of the steering column is rarely greater than the limits imposed by FMVSS 204. Figure 1 shows the distribution of the longitudinal steering column displacements. Figure 2 shows that rearward displacement of the steering column is correlated with rearward displacement of the instrument panel (R=0.81) and that large longitudinal steering wheel displacements tend to be associated with collapse of the occupant compartment. Lateral displacements of the steering wheel tend to be small and to the left in this crash condition. Vertical displacement of the steering column, although correlated with vertical movement of the instrument panel (R=0.81), is only weakly correlated with longitudinal movement of the instrument panel (R=-0.30), as shown in Figures 3 and 4, thus demonstrating that upward movement of the steering column can happen even in vehicles with strong occupant compartments.

Large vertical movements of the steering column in frontal offset crash tests often were associated with the dummy's head contacting the steering wheel through the airbag or other indications of suboptimal restraint system performance. Table 2 lists the crash tests in which head contact with the steering wheel was observed, along with measurements of steering column displacement and the resulting head acceleration and maximum head injury criterion (HIC). Some high head accelerations were recorded when the dummy's head hit the steering wheel, although the maximum HIC generally did not indicate an excessively high head injury risk. Nevertheless, these steering wheel contacts would be associated with an elevated risk of face or head injury compared with tests in which the dummy's head did not contact the steering wheel. The vertical steering column movement among these models was greater on average (11.5 cm) than vertical displacement in vehicles in which head contact with the steering wheel was not observed (8.1 cm). Among models with smaller steering column displacements, other factors were often the cause of steering wheel head contacts. For example, moderately large spool-out of seat belt webbing due to the action of seat belt force limiters was observed in tests of the 2000 BMW 3 series, 2000 Ford Taurus, 1999 Lexus GS 400, and 1998 Volkswagen New Beetle. In the 1999 Chrysler LHS, the airbag deployed late, after the dummy's head had contacted the steering wheel.

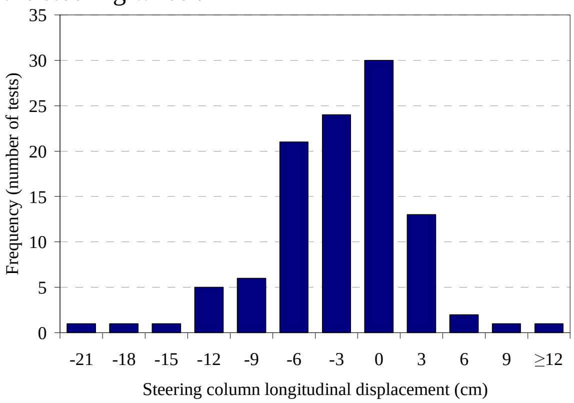

Figure 1. Distribution of Steering Column Longitudinal Displacements, IIHS 64 km/h frontal offset crash tests

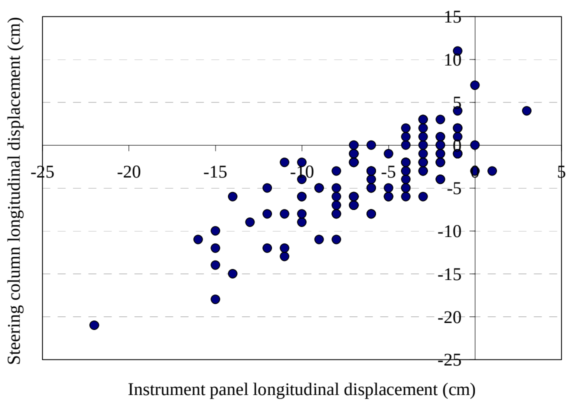

Figure 2. Steering Column Longitudinal Displacement is Correlated with Instrument Panel Longitudinal Displacement (R = 0.81)

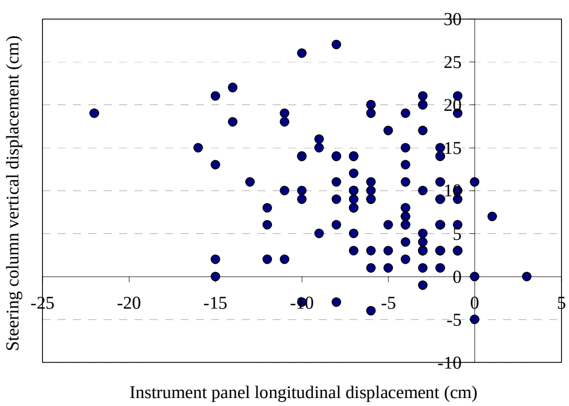

Figure 3. Steering Column Vertical Displacement is Weakly Correlated with Instrument Panel Longitudinal Displacement (R = -0.30)

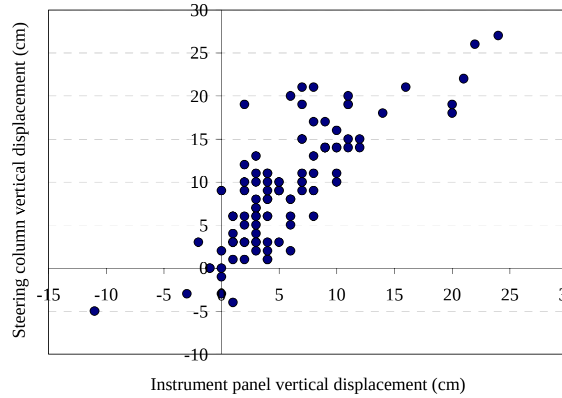

Figure 4. Steering Column Vertical Displacement is Correlated with Instrument Panel Vertical Displacement (R=0.81)

The fact that dummy head contacts with steering wheels often occur when there is significant vertical displacement of the steering wheel strongly suggests that this displacement can be an important contributor to the suboptimal performance of airbags in some crashes. Multipurpose passenger vehicles (MPVs), which include pickups, utility vehicles, and passenger vans, represent the majority of models listed in Table 2, despite the fact that fewer such models were tested (45 MPVs compared with 61 cars). The MPVs in Table 2 have larger vertical steering column displacements on average (16.0 cm) than cars (5.3 cm); rearward displacements were nearly the same for MPVs (-1.5 cm) and cars (-1.7 cm). The larger steering column vertical displacement observed in MPVs probably has something to do with the higher driver seating position heights in these vehicles compared with cars. The high seating height, combined with a relatively short longitudinal distance between the front axle and steering wheel, results in a more upright steering column angle than is typical in cars. In frontal crashes like these tests, the crash forces associated with the vehicle's deceleration are primarily horizontal and hence are not oriented to activate the column's collapsing mechanism. Instead, the rearward-directed force tends to rotate the column about its attachment point inside the occupant compartment. Table 3 shows that this tendency of MPVs to have larger vertical steering column displacements also is observed in the complete data set.

Several models have been redesigned and retested since IIHS first began conducting frontal offset crash tests (Table 4). Results for the redesigned models generally showed improved structural performance with considerably less deformation of the occupant compartment. In every case where occupant compartment integrity was improved, the longitudinal displacement of the steering wheel also was reduced. This is not a surprising result, because rearward intrusion of the steering column in modern designs is resisted by shear capsules, which are securely attached to the instrument panel. Vertical steering column displacements, however, were not necessarily reduced with other structural improvements. The 1998 Toyota Avalon, Mitsubishi Montero, Isuzu Rodeo, and Kia Sephia are among the models that exhibited improved occupant compartment strength compared with predecessor models, but considerable vertical movement of the steering column was observed in both the early and improved designs.

Table 2.
Tests with Head Contact Against Steering Wheel

	Steering Column Displacement (cm)		Head Acceleration (g)	HIC (15 ms)
	Longitudinal	Vertical		
1996 Chevrolet Astro	-5	8	31	152*
1996 Ford Aerostar	7	-5	81	267
1996 Mitsubishi Montero	1	17	84	508
1996 Nissan Quest	-6	14	74	251
1996 Toyota Previa	-7	27	91	552
1997 Mitsubishi Mirage	-8	10	82	207
1998 Dodge Dakota	-5	19	163	611
1998 Honda CR-V	-8	9	89	589
1998 Jeep Cherokee	2	19	60	273
1998 Nissan Frontier	-3	14	84	642
1998 Volkswagen New Beetle	2	3	85	354
1998 Volkswagen New Beetle	2	3	50	241
1999 Cadillac Catera	-5	7	46	148*
1999 Chrysler LHS	-8	6	95	739
1999 Lexus GS 400	-1	3	50	207*
1999 Nissan Quest	-15	22	73	442
2000 BMW 3 series	0	6	66	328
2000 Buick LeSabre	-2	3	75	409
2000 Dodge Intrepid	0	12	59	303
2000 Ford Focus	2	-1	54	183*
2000 Ford Taurus	-1	6	41	170*
2000 Isuzu Trooper	3	21	76	411
2000 Nissan Xterra	-2	15	96	617
2001 Isuzu Trooper	3	20	75	434
2001 Isuzu Trooper	2	21	74	390
2001 Mitsubishi Montero	11	19	72	397

*HIC interval does not include steering wheel contact.

Table 3.
Steering Column Displacement by Vehicle Type

	Longitudinal (cm)	Lateral (cm)	Vertical (cm)
Cars	-1	-4	6
MPVs	1	-3	13

REAL-WORLD CRASHES

Between 1987 and 2000, IIHS researchers investigated tow-away and injury-causing crashes in seven counties surrounding Charlottesville, Virginia (IIHS, 1992). One of the many crashes investigated during this period serves as an example of how steering column movement may degrade the protection of the driver airbag. The crash involved a 1992 Dodge Grand Caravan driven by a 51-year-old female who was using her lap/shoulder belt. The van crossed the road's centerline into the oncoming lane and collided with a 1994 Toyota pickup truck traveling in the opposite direction. This frontal offset crash was reconstructed with the CRASH3 computer program using damage measurements from both vehicles. The Grand Caravan's delta V was estimated to be 46 km/h, which is similar to CRASH3 delta V estimates using measurements from vehicles crashed at 64 km/h in the IIHS crashworthiness evaluation program (Nolan et al., 1998). The driver of the Grand Caravan died of an unspecified closed-head injury, according to the Virginia medical examiner's report. The only external injury noted in this and the hospital report was a laceration of the forehead, or forward portion of the scalp. The most likely source of the laceration, and possibly the brain injury, was the steering wheel rim, which was slightly bent and bore marks that may have been caused by the driver's head impact. Measurements of the crashed vehicle indicated the steering column was displaced 19 cm rearward and 6 cm rightward. A suitable reference for vertical displacement was not available, but Figure 5 shows that it was rotated upward considerably. It seems likely, especially noting the early movement of the steering column observed in the re-creation of the NASS case mentioned previously, that movement of the column in this crash contributed to the driver's head contacting the steering wheel. Another explanation for the driver's death is suggested by comparison with an IIHS crash test of a different model van, the 1997 Pontiac Trans Sport. The tested Trans Sport and the Grand Caravan from the seven-county study had similar levels of exterior deformation, with maximum crush measuring 98 and 100 cm, respectively. Steering column displacement in the Trans Sport was similar to that observed in the Grand Caravan, with 21 cm longitudinal displacement and 19 cm upward displacement (Figure 6). During the Trans Sport test, the dummy recorded

Table 4.
Vehicles That Were Redesigned and Retested

Vehicle	**Structure Evaluation**	**Left Lower Instrument Panel (cm) Longitudinal**	**Left Lower Instrument Panel (cm) Vertical**	**Right Lower Instrument Panel (cm) Longitudinal**	**Right Lower Instrument Panel (cm) Vertical**	**Steering Column (cm) Longitudinal**	**Steering Column (cm) Vertical**
1996 Toyota Avalon	Marginal	-9	9	-7	9	-6	14
1998 Toyota Avalon	Acceptable	-4	7	-6	8	-4	13
2000 Toyota Avalon	Good	-3	4	-2	4	-4	6
1996 Land Rover Discovery	Acceptable	-5	8	-6	9	-1	17
1999 Land Rover Discovery	Acceptable	-7	6	-8	7	-1	10
1997 Ford Escort	Acceptable	-8	0	-4	-2	-2	2
2000 Ford Focus	Acceptable	-3	0	-3	0	2	-1
1996 Jeep Grand Cherokee	Acceptable	-3	7	-2	4	-2	15
1999 Jeep Grand Cherokee	Marginal	-14	9	-11	11	-2	19
1997 Volkswagen Jetta	Marginal	-9	2	-7	2	-7	5
1999 Volkswagen Jetta	Acceptable	-8	-2	-7	-2	-6	3
1998 Nissan Maxima	Acceptable	-10	4	-7	1	-7	10
2000 Nissan Maxima	Acceptable	-8	0	-6	-2	-8	9
1996 Mitsubishi Montero	Acceptable	-4	8	-3	7	1	17
2001 Mitsubishi Montero	Good	-1	2	-2	1	11	19
1996 Mazda MPV	Marginal	-14	9	-9	10	-5	16
2000 Mazda MPV	Acceptable	-4	7	-6	8	-2	6
1997 Dodge Neon	Marginal	-14	6	-11	1	-13	2
2000 Dodge Neon	Marginal	-13	3	-12	1	-12	2
1996 Honda Odyssey	Poor	-10	17	-12	22	-2	26
1999 Honda Odyssey	Acceptable	-2	7	-1	6	1	10
1996 Toyota Previa	Poor	-8	14	-12	24	-7	27
1998 Toyota Sienna	Good	-2	2	-3	1	-2	3
1997 Mazda Protege	Acceptable	-6	4	-2	3	1	9
1999 Mazda Protege	Acceptable	-6	0	-4	1	-3	4
1996 Nissan Quest	Acceptable	-12	11	-8	12	-6	14
1999 Nissan Quest	Poor	-19	21	-14	19	-15	22
1996 Isuzu Rodeo	Poor	-17	15	-15	16	-12	21
2000 Isuzu Rodeo	Good	-1	2	-1	0	4	9
1998 Nissan Sentra	Marginal	-8	1	-4	-1	-5	6
2000 Nissan Sentra	Acceptable	-7	1	-5	1	-6	1
1997 Kia Sephia	Poor	-12	11	-9	7	-5	15
1999 Kia Sephia	Marginal	-6	3	-6	3	0	10
1997 Cadillac Seville	Poor	-16	12	-16	11	-11	15
2000 Cadillac Seville	Good	-4	3	-3	2	-2	4
1996 Hyundai Sonata	Poor	-11	-3	-8	-5	-11	-3
1999 Hyundai Sonata	Marginal	-12	-1	-10	0	-9	-3

moderately high neck tension (2.7 kN) and quite high neck bending torque (106 Nm) when its head interacted with the driver airbag on the end of the moving steering column. These forces, although not indicating a certainty of injury, might be associated with an elevated risk of cervical spine or basal skull injury. Thus, contact with the unprotected steering wheel is only one way in which the steering column movement might degrade airbag performance.

IIHS researchers recently undertook an examination of frontal crashes of airbag-equipped cars that were fatal to the drivers of those cars (Zuby et al., 2001). The objective of the study was to categorize each crash according to the primary cause of each driver's fatal injuries. The study found that major collapse of the occupant compartment, combined with contacting a specific intruding component, accounted for most driver deaths (41 percent). There also were a large number of cases (21percent) in which more than one primary cause were equally reasonable explanations for the driver's death. Among these 72 cases, the steering wheel was frequently assigned as an injury source by the NASS investigators. A case from 1998, for example, involved a 1995 Ford Escort driven by a 51-year-old female that collided with a 1988 Honda Accord traveling in the opposite direction (case 49-151A). Despite a rather high estimated delta V (86 km/h), the steering wheel displacement recorded by the investigator (12 cm) was slightly less than the limit imposed by FMVSS 204. Figure 7 shows that in addition to this rearward movement, the column was rotated upward. Still, the steering wheel was bent, suggesting that it was loaded by the driver, who was using the automatic shoulder belt but not the lap belt. Her injuries included broken ribs and significant contusions of the heart and lungs. Another crash (case 11-135J from 1998) involved a severe frontal crash (estimated delta V of 63 km/h) between a 1998 Dodge Dakota pickup and a tree. The 16-year-old driver, who was using his seat belt, died of closed-head injuries for which the NASS investigator did not assign an impact cause. However, comparison with an IIHS crash test of the same model vehicle suggests that movement of the steering column may have led to contact with the steering wheel through the airbag. Delta V estimates from the SMASH computer program suggest that the IIHS 64 km/h frontal offset test was less severe (estimated delta V of 48 km/h) than the NASS crash, yet high neck forces (3.9 kN tension) and head acceleration (163 g) were recorded when the dummy's head contacted the steering wheel. Consequently, with even greater steering column displacement (10 cm rearward, unmeasured upward) than observed in the crash test (5 cm rearward, 19 cm upward), it seems plausible that the driver in the NASS crash sustained his fatal head injuries in a similar way. Although the timing of injury-causing events in real-world crashes cannot be known with any certainty, comparison with crash tests having similar conditions suggests that movement of the steering column can be an important factor influencing the ability of driver airbags to prevent serious injuries in real crashes.

Figure 5. Steering Column of Dodge Grand Caravan in Crash from IIHS Study was Rotated Upward Considerably

Figure 6. Steering Column in Pontiac Tran Sport Crashed by IIHS was Rotated Upward 19 cm

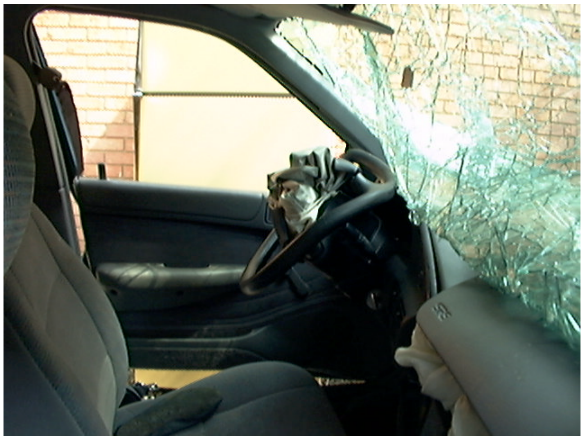

Figure 7. Steering Column in Ford Escort from 1998 NASS case 49-151A was Rotated Upward Considerably and Bent by Driver Contact

DISCUSSION

Steering column movement during severe frontal crashes and the efficacy of relevant safety regulations has been the subject of considerable prior research. Some investigators recommended changing FMVSS 203 and 204 to address shortcomings of compliant steering systems identified in real crashes (Gloyns et al., 1980). However, the advent of regulations requiring airbags in cars sold in the United States has distracted attention from the important role of the steering system in occupant protection. This is likely due in part to the fact that in full-width rigid barrier tests at 48 and 56 km/h, steering column movement is not such a significant issue. However, IIHS frontal offset tests of new cars show that movement of the steering column during the crash can contribute to suboptimal performance of the driver airbag. Steering column movement in real-world crashes is also related to many instances of serious and fatal injuries attributed to contact with the steering wheel in airbag-equipped cars. Clearly, more attention should be paid to steering system designs to ensure that they provide a stable platform for driver airbags in a wide range of frontal crash conditions.

As long as steering wheels continue to be mechanically connected to the front wheels of passenger vehicles, techniques like those described by Fileta and Liu (1997) must be used to understand the influence of crush zone structures on steering wheel movement. These engineers identified the critical structures influencing steering column movement by conducting crushing tests that simulated different crash modes and developed alternate designs that were effective in controlling this movement in a popular midsize car. Improved safety regulations like the new European frontal crash regulation (Directive 96/79/EC), which is based on a frontal offset crash test and limits both horizontal and vertical steering column movement, may be required to ensure more widespread use of such techniques in steering system design. However, advances in electronic control may promise even greater improvements. Without a mechanical connection between the steering wheel in the occupant compartment and the front wheels of the car, the stability of the driver airbag would solely depend on occupant compartment structural integrity, which IIHS (2001b) crash tests show is improving. According to an article in *The Wall Street Journal*, this technology is being developed by BMW, DaimlerChrysler, and other automobile manufacturers (Miller, 2001). Perhaps consideration of crashworthiness improvements can provide further impetus for the development of these drive-by-wire systems.

ACKNOWLEDGMENT

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REFERENCES

Arbelaez, R.A. and O'Neill, B. 2001 Difficulties in determining the cause of real-world crash injuries: a case study of a NASS investigation. *Proceedings of the 17th International Technical Conference on the Enhanced Safety of Vehicles* (CD ROM). Washington, DC: National Highway Traffic Safety Administration.

Augenstein, J.S. et al. 1995. Chest and abdominal injuries suffered by restrained occupants (SAE 950657). *Advances in Occupant Protection Technologies for the Mid 90's* (SP-1077), 37-44. Warrendale, PA: Society of Automotive Engineers.

Fileta, B. and Liu, X. 1997. Intrusion factors and their effects on steering column movements during vehicle's frontal impact testing. SAE Technical Paper Series 970573. Warrendale, PA: Society of Automotive Engineers.

Gloyns, P.F.; Hayes, H.R.M.; and Rattenbury, S.J. 1980. Protection of the car driver from steering system induced injuries. *Towards Safer Passenger Cars*, 23-29. London, England: Institute of Mechanical Engineering.

Insurance Institute for Highway Safety. 1992. *Status Report Special Issue: Crash Investigations in Detail* 27(13). Arlington, VA.

Insurance Institute for Highway Safety. 2000. Crashworthiness evaluation offset barrier crash test protocol, ver. 8. Arlington, VA.

Insurance Institute for Highway Safety. 2001a. Airbag statistics. Arlington, VA. Available: http://www. highwaysafety.org/safety_facts/airbags/stats.htm.

Insurance Institute for Highway Safety. 2001b. *Status Report Special Issue: Crashworthiness Improvements* 36(3). Arlington VA. Available: http://www.highwaysafety.org/srpdfs/sr3603.pdf.

Kahane, C.J. 1982. Evaluation of current energy-absorbing steering assemblies (SAE 820473). *Occupant Crash Interaction with the Steering System* (SP 507), 45-49. Warrendale, PA: Society of Automotive Engineers.

Miller, S. 2001. 'Drive-by-wire' technology promises simpler and safer car control: BMW, DaimlerChrysler develop electronic steering systems; the joystick vs. the wheel. *The Wall Street Journal* (January 12):B1.

Nolan, J.M.; Preuss, C.A.; Jones, S.L.; and O'Neill, B. 1998. An update on the relationships between computed delta Vs and impact speeds for offset crash tests. *Proceedings of the 16th International Technical Conference on the Enhanced Safety of Vehicles*, 2:1234-41. Washington, DC: National Highway Traffic Safety Administration.

Zuby, D.S.; Cammisa, M.X.; and Ferguson, S.A. 2001. Analysis of driver fatalities in frontal crashes of airbag-equipped vehicles in 1990-98 NASS/CDS. SAE Technical Paper Series 2001-01-0156. Warrendale, PA: Society of Automotive Engineers.

APPENDIX

			Insturment Panel (cm)				Steering Column (cm)						
Test ID	**Year Make Model**	**Test Weight (kg)**	**Left Horizontal**	**Left Vertical**	**Right Horizontal**	**Right Vertical**	**Horizontal**	**Lateral**	**Vetrical**	**Seat Belt Spool-out (cm)**	**HIC (15 ms)**	**Neck Tension (kN)**	**Neck Extension (Nm)**
CF95031	1996 Toyota Avalon	1,584	-9	9	-7	9	-6	5	14	9	274	1.4	26
CF96001	1996 Jeep Grand Cherokee	1,850	-3	7	-2	4	-2	4	15	7	553	1.7	18
CF96002	1996 Chevrolet Blazer	2,013	-16	20	-14	18	-6	3	18	8	826	2.3	55
CF96003	1996 Land Rover Discovery	2,134	-5	8	-6	9	-1	-3	17	—	629	1.4	37
CF96004	1996 Isuzu Rodeo	2,030	-17	15	-15	16	-12	-1	21	10	570	2.7	30
CF96005	1996 Toyota 4-Runner	1,924	-2	7	-3	9	3	3	14	—	463	1.8	23
CF96014	1996 Mitsubishi Montero	2,162	-4	8	-3	7	1	-2	17	4	508	1.9	40
CF96015	1996 Dodge Grand Caravan	2,002	-10	5	-10	4	-4	-1	9	—	534	2.1	28
CF96017	1996 Hyundai Sonata	1,485	-11	-3	-8	-5	-11	-6	-3	7	257	1.9	15
CF96018	1996 Mazda MPV	1,852	-14	9	-9	10	-5	0	16	3	202	1.9	35
CF96020	1996 Nissan Quest	1,862	-12	11	-8	12	-6	5	14	1	251	2.6	14
CF96021	1996 Honda Odyssey	1,702	-10	17	-12	22	-2	3	26	4	173	1.6	30
CF96022	1996 Toyota Previa	1,874	-8	14	-12	24	-7	5	27	—	552	3.9	41
CF96023	1996 Ford Aerostar	1,815	-1	-11	0	-12	7	29	-5	3	267	2.7	34
CF96024	1996 Chevrolet Astro	2,131	-13	3	-12	0	-5	-1	8	—	152	1.4	8
CF96026	1997 Pontiac Transsport	1,852	-27	20	-22	18	-21	-8	19	8	311	2.7	117

			Insturment Panel (cm)				Steering Column (cm)						
Test ID	**Year Make Model**	**Test Weight (kg)**	**Left Horizontal**	**Left Vertical**	**Right Horizontal**	**Right Vertical**	**Horizontal**	**Lateral**	**Vetrical**	**Seat Belt Spool-out (cm)**	**HIC (15 ms)**	**Neck Tension (kN)**	**Neck Extension (Nm)**
CF96027	1997 Pontiac Grand Prix	1,711	-10	11	-10	11	-6	1	14	—	627	2.2	46
CF96028	1997 Toyota Camry	1,558	-3	2	-3	3	-2	2	5	4	422	1.4	23
CF96029	1997 BMW 5 series	1,876	-4	4	-4	3	1	3	8	11	299	1.4	17
CF96031	1997 Lexus LS	1,886	-3	4	-4	4	-6	-2	1	5	414	1.5	22
CF97001	1997 Cadillac Seville	1,910	-16	12	-16	11	-11	2	15	3	214	1.5	25
CF97002	1997 Nissan Pathfinder	2,060	-15	3	-15	3	-10	7	13	3	607	1.8	39
CF97005	1997 Mercedes-Benz E class	1,802	-5	4	-3	5	-3	2	10	8	305	2.0	19
CF97006	1997 Lincoln Continental	1,914	-13	3	-12	4	-8	0	6	8	248	1.6	40
CF97007	1997 Infiniti Q45	1,944	-8	6	-4	4	-6	0	8	—	786	2.3	24
CF97008	1997 Infiniti Q45	1,944	-10	7	-6	4	-8	-1	9	6	841	2.4	29
CF97009	1997 Honda Civic	1,244	-7	1	-5	-1	-6	3	6	2	241	2.0	15
CF97011	1997 Mitsubishi Mirage	1,231	-11	5	-12	2	-8	-4	10	—	207	1.7	21
CF97013	1997 Kia Sephia	1,316	-12	11	-9	7	-5	3	15	5	374	2.2	20
CF97015	1997 Saturn S series	1,240	-13	6	-9	3	-11	0	5	6	229	1.5	13
CF97016	1997 Ford Escort	1,294	-8	0	-4	-2	-2	1	2	3	457	1.6	19
CF97017	1997 Mazda Protege	1,272	-6	4	-2	3	1	1	9	—	324	1.6	22
CF97018	1997 Volkswagen Jetta	1,365	-9	2	-7	2	-7	4	5	1	383	1.4	18
CF97019	1997 Dodge Neon	1,308	-14	6	-11	1	-13	-11	2	—	265	2.1	23
CF97020	1997 Hyundai Elantra	1,355	-8	4	-6	4	-5	-2	1	—	301	2.1	28
CF97021	1998 Nissan Sentra	1,281	-8	1	-4	-1	-5	0	6	2	280	1.8	19
CF97022	1998 Toyota Corolla	1,284	-6	1	-8	4	-4	1	11	1	318	1.8	18
CF97023	1998 Toyota Avalon	1,680	-4	7	-6	8	-4	6	13	1	204	1.2	16
CF97024	1998 Nissan Maxima	1,550	-10	4	-7	1	-7	1	10	—	309	1.6	31
CF97026	1998 Toyota Sienna	1,928	-2	2	-3	1	-2	1	3	10	205	0.8	10
CF98001	1998 Honda Accord	1,526	-2	3	-2	3	-1	2	6	4	169	1.3	13
CF98002	1998 Volkswagen Passat	1,576	-8	4	-7	5	-2	-2	9	0	160	1.7	10
CF98003	1998 Toyota Tacoma	1,380	-2	3	-3	5	1	4	9	6	670	1.8	14
CF98004	1998 Chevrolet S-10	1,569	-19	3	-15	4	-14	-1	2	8	281	1.7	25
CF98005	1998 Nissan Frontier	1,518	-8	9	-8	8	-3	5	14	5	642	1.8	13
CF98006	1998 Dodge Dakota	1,758	-8	10	-6	11	-5	-1	19	16	611	3.9	53
CF98007	1998 Ford Ranger	1,584	-7	4	-8	4	-2	3	8	10	307	2.2	25

			Instrument Panel (cm)				Steering Column (cm)						
Test ID	**Year Make Model**	**Test Weight (kg)**	**Left Horizontal**	**Left Vertical**	**Right Horizontal**	**Right Vertical**	**Horizontal**	**Lateral**	**Vetrical**	**Seat Belt Spool-out (cm)**	**HIC (15 ms)**	**Neck Tension (kN)**	**Neck Extension (Nm)**
CF98008	1998 Jeep Wrangler	1,594	1	3	1	3	-3	-5	7	4	335	2.1	18
CF98009	1998 Volkswagen New Beetle	1,378	-2	1	-1	0	2	0	3	14	354	1.5	29
CF98010	1998 Volkswagen New Beetle	1,377	-2	1	-1	1	2	0	3	16	241	1.3	18
CF98012	1998 Jeep Cherokee	1,701	-4	7	-4	7	2	2	19	3	273	2.3	32
CF98013	1998 Kia Sportage	1,652	0	7	-4	3	-3	1	11	—	457	2.3	28
CF98014	1998 Toyota RAV4	1,498	-2	3	-4	3	-4	-1	11	2	407	1.8	26
CF98016	1998 Isuzu Amigo	1,758	-17	14	-11	11	-12	-4	18	5	475	2.0	31
CF98017	1998 Honda CR-V	1,577	-8	8	-14	7	-8	6	9	2	589	2.3	32
CF98018	1999 Subaru Forester	1,549	-6	1	-5	0	-5	1	3	6	201	1.7	19
CF98019	1999 Mitsubishi Galant	1,511	-7	5	-7	6	-1	-2	8	8	336	1.9	18
CF98020	1999 Suzuki Grand Vitara	1,593	-5	2	-2	1	0	-1	1	3	658	2.4	38
CF98021	1999 Saab 9-5	1,734	-5	2	-2	1	-1	-1	3	0	289	1.2	20
CF98022	1999 Lexus RX 300	1,900	-3	3	-4	2	-3	2	3	4	184	1.0	12
CF98023	1999 Nissan Quest	1,936	-19	21	-14	19	-15	3	22	3	442	1.5	27
CF98024	1999 Honda Odyssey	2,078	-2	7	-1	6	1	2	10	4	166	1.2	15
CF99001	1999 Volkswagen Jetta	1,455	-8	-2	-7	-2	-6	-4	3	8	140	1.3	17
CF99002	1999 Ford Windstar	1,992	-6	10	-4	9	-3	2	11	9	183	1.1	22
CF99003	1999 Hyundai Sonata	1,544	-12	-1	-10	0	-9	-4	-3	0	275	1.4	11
CF99004	1999 Saab 9-3	1,567	-8	9	-7	10	-6	0	14	4	334	1.4	26
CF99005	1999 Mazda Protege	1,302	-6	0	-4	1	-3	-2	4	8	230	2.2	33
CF99006	1999 Lexus GS	1,824	-3	1	-5	0	-1	-1	3	14	207	1.6	28
CF99007	2000 Dodge Neon	1,319	-13	3	-12	1	-12	-6	2	13	449	2.7	17
CF99008	1999 Kia Sephia	1,308	-6	3	-6	3	0	3	10	4	821	2.3	29
CF99009	1999 Jeep Grand Cherokee	1,920	-14	9	-11	11	-2	-3	19	11	351	2.2	20
CF99010	1999 Land Rover Discovery	2,314	-7	6	-8	7	-1	2	10	9	312	1.6	21
CF99011	1999 Mitsubishi Montero Sport	1,990	-11	10	-10	9	-8	-3	10	4	404	2.5	48
CF99012	1999 Mercedes-Benz M class	2,125	-2	2	-1	2	-1	-2	3	0	308	2.4	34
CF99013	1999 Dodge Durango	2,312	-8	11	-6	11	-3	-1	20	13	412	2.2	34
CF99014	2000 Chevrolet Impala	1,676	-6	3	-7	2	-3	2	3	12	204	1.2	13
CF99015	2000 Buick LeSabre	1,728	-3	5	-3	5	-2	-1	3	5	409	1.6	16

			Instrument Panel (cm)				Steering Column (cm)						
Test ID	**Year Make Model**	**Test Weight (kg)**	**Left Horizontal**	**Left Vertical**	**Right Horizontal**	**Right Vertical**	**Horizontal**	**Lateral**	**Vetrical**	**Seat Belt Spool-out (cm)**	**HIC (15 ms)**	**Neck Tension (kN)**	**Neck Extension (Nm)**
CF99016	1999 Cadillac Catera	1,842	-7	3	-4	1	-5	-9	7	6	148	1.6	18
CF99017	1999 Audi A6	1,822	-7	2	-9	2	-2	0	10	4	168	1.1	24
CF99018	2000 Dodge Intrepid	1,692	-7	2	-7	1	0	0	12	14	303	2.3	19
CF99019	1999 Buick Park Avenue	1,840	-4	4	-3	4	0	1	3	5	306	1.6	22
CF99020	1999 Chrysler LHS	1,737	-10	6	-8	4	-8	-3	6	13	739	3.6	21
CF99021	2000 Cadillac Seville	1,916	-4	3	-3	2	-2	0	4	5	188	1.1	15
CF99022	2000 Saturn L series	1,565	-5	3	-4	2	0	3	7	18	236	1.8	17
CF99024	1999 Mazda 626	1,416	-7	1	-6	1	-3	-4	-4	4	383	1.7	35
CF99025	1999 Chevrolet Malibu	1,500	-11	7	-8	8	-5	-3	11	6	466	1.4	47
CF99026	1999 Pontiac Grand Am	1,513	-13	10	-10	10	-6	-3	14	6	331	1.7	26
CF00003	1999 Daewoo Leganza	1,574	-15	-1	-15	-1	-18	-4	0	0	672	2.1	21
CF00004	2000 Nissan Altima	1,512	-15	4	-13	1	-9	-6	11	0	316	1.3	20
CF00005	2000 Subaru Legacy	1,600	0	-1	-1	-2	0	3	0	8	209	2.1	21
CF00006	2000 BMW 3 series	1,620	-5	2	-2	1	0	1	6	18	328	1.5	9
CF00007	2000 Volvo S80	1,715	-4	1	-2	0	-2	-5	3	0	188	1.3	38
CF00010	2000 Ford Taurus	1,622	-2	3	-1	3	-1	-1	6	13	170	1.4	13
CF00011	2000 Mazda MPV	1,775	-4	7	-6	8	-2	-2	6	7	693	2.8	29
CF00012	2000 Toyota Avalon	1,677	-3	4	-2	4	-4	1	6	7	377	1.8	43
CF00014	2000 Isuzu Rodeo	1,946	-1	2	-1	0	4	2	9	3	884	2.7	31
Cf00015	2000 Nissan Maxima	1,624	-8	0	-6	-2	-8	0	9	4	333	2.0	25
CF00016	2000 Nissan Sentra	1,324	-7	1	-5	1	-6	-4	1	0	428	1.6	39
Cf00017	2000 Lincoln LS	1,837	1	0	3	-3	4	-7	0	12	333	1.8	18
CF00020	2000 Nissan Xterra	1,998	-4	5	-10	7	-2	2	15	8	617	2.4	35
CF00021	2000 Isuzu Trooper	2,100	-3	6	-3	8	3	1	21	18	411	2.5	33
CF00022	2001 Mitsubishi Montero	2,264	-1	2	-2	1	11	0	19	9	397	1.9	24
CF00023	2001 BMW X5	2,168	-2	3	-1	3	-1	-1	3	23	177	1.2	13
CF00024	2001 Isuzu Trooper	2,126	-3	5	-4	6	3	3	20	19	434	2.0	35
CF00025	2000 Ford Focus	1,350	-3	0	-3	0	2	-1	-1	11	183	1.7	35
CF00029	2001 Isuzu Trooper	2,124	-2	6	-1	7	2	2	21	17	390	2.1	24

— No measurement was recorded.